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QA Inspections Via Condition Monitoring

Investigation of Sensor/Measurement Systems for Army Installation Quality Assurance Applications

by
James H. Johnson
Marc J. Poskin

As the U.S. Army downsizes and many experienced personnel leave the service, installation Directorates of Engineering and Housing (DEHs) must necessarily fulfill their mission with lower operating budgets and less experienced technical personnel. A key DEH function significantly affected by this trend is the quality assurance (QA) program. Historically, key QA inspections have been performed through the eyes and ears of highly experienced personnel. Although such procedures by experienced personnel are time-tested and effective, changing conditions require the upgrading of inspection methods. Today's inspectors must make quantifiable, reproducible QA judgments at the lowest possible cost. To successfully accomplish this, they need aids that can reliably measure and document the parameters being inspected. One way to successfully meet the rigorous demands posed by the realities of the modern Army and changing technology is through new QA applications of sensor/measurement (S/M) systems.

This report describes 14 commercially available S/M systems with potentially valuable applications in Army QA activities, and reports the results of field evaluation by several installation DEHs and Corps of Engineers laboratories. Most of the systems tested were found by the evaluators to be fully applicable to appropriate QA activities with few or no reservations.

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This report describes 15 commercially available S/M systems with potentially valuable applications in Army QA activities, and reports the results of field evaluation by several installation DEHs and Corps of Engineers laboratories. Most of the systems tested were found by the evaluators to be fully applicable to appropriate QA activities with few or no reservations.

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FOREWORD

This study was conducted for the U.S. Army Center for Public Works (USACPW) under Project 4A162784AT41, "Military Facilities Engineering Technology"; Work Unit SB-A51, "QA Inspections Via Condition Monitoring." The technical monitor was Robert Hohenberg, CECPW-FM-A.

The work was performed by the Facility Management Division (FF) of the Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The principal investigator was James H. Johnson. Alan W. Moore is Acting Chief, CECER-FF, and Dr. Michael J. O'Connor is Chief, CECER-FL.

LTC David J. Rehbein is Commander of USACERL and Dr. L.R. Shaffer is Director.

CONTENTS

TABLES

INVESTIGATION OF SENSOR/MEASUREMENT SYSTEMS FOR ARMY INSTALLATION QUALITY ASSURANCE APPLICATIONS

1 INTRODUCTION

Background

As the U.S. Army downsizes and many experienced personnel leave the service, installation Directorates of Engineering and Housing (DEHs) must necessarily fulfill their mission with lower operating budgets and less experienced technical personnel. A key DEH function significantly affected by this trend is the quality assurance (QA) program.

The installation's QA program ensures that the Army "gets what it pays for" in real property maintenance activity (RPMA) services performed by private-sector contractors. When the Army contracts for RPMA services, the quantity and quality of the delivered service must be verified. Although service contractors usually are required to maintain a quality control (QC) program, QA surveillance by the Army is necessary to verify and document the contractor's performance.

Historically, key QA inspections have been performed by journeyman craftsmen who inspected essential equipment by looking and listening, then evaluated it using their seasoned judgment. Newer inspectors sometimes must make QA judgments on the basis of less experience. Furthermore, innovative technologies may lead to Army installations that feature intelligent buildings, self-correcting utility systems, and automated service systems that will require more technically advanced, detailed, accurate, and timely inspection methods.

One way to meet the QA demands posed by the realities of the modern Army and changing technology may be through the application of new sensor/measurement (S/M) systems being developed and adopted by industry. S/M systems could enhance the observations and judgments of any inspector who learns how to use such devices. A greater need than ever now exists for accurate and reliable S/M systems to support QA inspection processes. In the work reported here, the U.S. Army Construction Engineering Research Laboratories (USACERL) identified a number of S/M systems that could be used off-the-shelf to enhance the effectiveness of DEH QA inspections.

Objective

The objective of this research was to identify and evaluate commercially available S/M systems that may improve the accuracy, efficiency, and repeatability of QA inspections by DEH personnel.

Approach

General inspection-related needs were determined through an informal survey of several installation DEHs. Potential specific S/M applications were identified through discussions of the survey with DEH personnel. S/M devices available through commercial or industrial sources were investigated to identify candidate systems for enhancing QA inspections of contracted RPMA at Army installations. Trends and mainstream developments in S/M technology that may in the future be useful in performing DEH QA activities were also considered. Field evaluations of candidate systems were arranged with three

installation DEHs, the U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL), and USACERL. Comments about the devices tested by management and hands-on users in the field were compiled, interpreted, and documented.

Principal technical terms related to S/M systems are defined in a glossary starting on page 40.

Mode of Technology Transfer

This research has resulted in a plan to establish a Corps of Engineers "lending library" of the most-needed S/M systems for installation QA programs. This library, or equipment bank, will give installations access to sophisticated S/M systems without the expense of buying them outright. A catalog of the equipment bank's inventory is being prepared for distribution to Army installation DEHs. Information from this study on field-evaluated inspection systems, as well as future comments by field users, will be the basis for revising QA inspection procedures at the installation level.

2 DEH QA NEEDS AND POTENTIAL S/M APPLICATIONS

Before identifying the S/M systems most likely to enhance the effectiveness of QA activities, an outline of the DEH's division of responsibilities is required to help define the nature and scope of the inspection needs.

The Army Maintenance Organization

Contracted facility and equipment maintenance at Army installations is generally planned, directed, supervised, and coordinated by the local DEH, a contracts officer, and QA management team. A typical DEH division of responsibilities is shown in Appendix A.

In the example shown in Appendix A, the Engineer Resource Management Division (ERMD) monitors service orders (SOs), standing operation orders (SOOs), and small or routine individual job orders (IJOs). The Engineering Planning and Services Division (EP&S) is responsible for scheduling and administering QA inspections of large or nonroutine IJOs. The purpose of these inspections is to assess the overall condition of the facility, its components, associated equipment, and supplied utility services. The Buildings and Grounds (B&G) Division performs interior and exterior maintenance-related inspections, and the Utilities Division maintains interior and exterior utility distribution systems.

Criteria for Usefulness

Through QA inspector user meetings, telephone interviews of DEH personnel, an informal field survey (Appendix B), and field evaluation of equipment, the authors developed a list of "required" and "needed" S/M system characteristics most important to DEH management and inspection personnel. *Required* characteristics are defined as those that are essential to an effective QA inspection program. *Needed* characteristics are defined as those which, while not essential, are most wanted by management and inspection personnel to support technical competence and improve effectiveness. In addition to the required and needed attributes, the authors identified power supply and datalogging capabilities as two characteristics that heavily determine how useful an S/M system is as a QA inspection tool.

Required Characteristics

Five attributes were identified as required characteristics for any S/M system to be used in Army QA applications:

1. Portability. The instrumentation should not be a burden to move and operate in the field. For larger instrumentation systems, a portable cart or lightweight body harness may provide the needed portability. When access to the item being inspected requires a ladder, the instrumentation must not constitute a safety hazard to the inspector.

2. Ease of Use. The instrumentation must be easy for technicians to use. Operation should be easy enough to be communicated in brief, simple instructions. When the instrumentation system is technically advanced, a short training program provided by the manufacturer or distributor would be solicited.

3. Ease of Interpretation. The system should provide inspection information that is straightforward and readily understandable by the inspector. When the system provides information that is complex out of necessity, a training course or contracted analytical support services may be necessary.

4. Durability. The instrumentation must be able to withstand the field environments in which they will be used, and must also be able to handle the jostling they will receive during normal handling in the field.

5. Accuracy. The instrumentation must be consistently accurate, with a margin of error no greater than ± 5 percent.

Needed Characteristics

1. Lightweight and Hand-Holdable. A system with these characteristics avoids distracting the inspector from his or her primary inspection and measurement duties. (It should be noted that hand-held probes, while convenient, can be hazardous when used near moving machinery.)

2. Multifunctional. Instruments that can measure or assess more than one property promote scheduling flexibility, inspection efficiency, cost effectiveness. For example, the Solomat HVAC system evaluated in this study measures and records air temperature, air velocity, and relative humidity. Compact multifunctional systems enable a single inspector to accomplish more with less.

S/M Power Requirements

While not addressed as a required or needed characteristic in the needs survey, portable power systems are often essential if an S/M system is to be practical for QA applications in the field. Lightweight battery packs—either single-use or rechargeable—offer inspectors maximum flexibility in the field. A system that relies on a power cord is restricted in mobility, and the cord may present a safety hazard for the user.

Datalogging and Processing Considerations

To take full advantage of the information provided by sensors and instruments used in QA inspections, the S/M system should be able to log (record) the data and later download it to a personal computer (PC). The information recorded by these systems can be highly valuable to DEH management, especially when combined with the analytical power available through computer software such as engineered management systems. Historical records of facility and equipment status are easily built from these measurement records, and software can help management dedicate appropriate resources to the facilities that most need it. An automated maintenance status capability will facilitate management operations and result in a more efficient maintenance program.

Potential Areas of Application for S/M Systems

While the potential benefits of S/M systems are substantial, not all work inspected by the DEH would be appropriate for S/M applications. In general, two O&M areas have the most potential applications: (1) utilities O&M and (2) building O&M.

Potential S/M inspection application areas for utilities include:

- Water services
- Sewage services
- Gas services
- Electric services
- Heating services
- Cooling services.

Potential S/M inspection application areas for buildings include:

- Electrical work
- Plumbing work
- Metal work
- Carpentry
- Masonry and concrete
- Painting work
- Gutters and drainage systems.

Appendix C outlines some of the most common specific inspection needs in each of the above application areas.

3 SELECTION AND FIELD EVALUATION OF QA INSTRUMENTATION

For this study, 14 S/M systems were selected on the basis of their potential to improve QA inspection operations. Most of the systems selected were chosen at the request of DEHs polled by the authors; several others were selected by USACERL.

Participating Sites

Three installations—Fort Meade, MD; Fort Monmouth, NJ; and Fort Ritchie, MD—participated in the field evaluation of the S/M systems selected for study (next section). These installations only field-tested systems that were of interest to their DEHs or QA managers. Two Corps of Engineers Laboratories—the U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL) and USACERL—used and evaluated selected systems for live inspection tasks within their respective facilities.

Systems Selected

The authors reviewed catalogs and industry directories to compile a log of S/M instrumentation suppliers (Appendix D). From this, a list of available and potentially useful S/M systems was developed. The list was sent to the participating installations with the other materials provided by USACERL for the DEH user needs survey.

DEH-Requested Instrumentation

Below are listed the systems most requested by DEH respondents. A minimum of two separate DEH requests for an instrument was required before USACERL would consider acquiring that instrument. (The items below are listed in order of DEH interest level.)

1. *Tooke Gage Mark IV Coating Thickness Gage.* Permits direct measurement of coating thickness. Also allows determination of a coating's adhesion characteristics and inspects substrate conditions by means of a scratch-all and spyglass. Applicable to most surface inspections for coatings and substrates that can tolerate a 4 cm scratch.

2. *Solomat MPM 2000 with 2016 Modumeter and Datalogger.* Measures air temperature, air velocity, and relative humidity, and stores the measurements into an integral datalogger; includes capability to download data to a PC. A rechargable battery pack and carrying case are required.

3. *Positector 2000 Coating Thickness Gage.* Quickly and nondestructively measures the thickness of any coating over a ferrous (iron-containing) substrate. This is a direct-readout palm-sized instrument that has no attachment requirements.

4. *Amprobe Current Tracer Kit Model CT-23.* Locates and traces energized conductors (e.g., electrical, telephone, computer lines) in walls and floors. This is a complete palm-sized unit with both light and audio signals.

5. *Hanna Instruments pH/Temp Meter Model HI8414.* Directly measures pH (acidity or alkalinity) and temperature levels of solutions. Simple probe-protection procedures must be followed to avoid damaging the instrument.

6. *Kernco Bearing Condition Indicator (BECI) Model 54A11.* Uses vibration sensors to detect the relative condition of roller bearings in motors. This is a stand-alone hand-held unit, but it has no datalogging capabilities.

7. *TIF Halogen Leak Detector Model 5000.* Detects and locates halogen gas leaks in refrigeration systems. It is a hand-held integrated unit that alerts the user with an auditory signal.

8. *Amprobe Ultrasonic Leak Detector Model ULD-100.* Detects and locates sources of ultrasonic "noise," including air, vacuum, steam, and gas leaks in HVAC systems. Offers expanded capabilities when paired with the ultrasonic transmitter described in item 9 below.

9. *Amprobe Ultrasonic Transmitter Model UT-200.* Locates cracks and anomalies in unpressurized pipes and conduits; generates the ultrasound used with the detector described in item 8 above.

Additional Instrumentation Systems Investigated

In addition to the systems selected by the installations DEHs polled, USACERL investigated five other systems in a field environment for their potential effectiveness in inspection-related applications, and offered them for DEH testing:

1. *Walker Scientific Gaussmeter.* Measures magnetic field densities (in gauss units) around electric motors. The readings from this hand-held, direct-readout unit can provide early warning of electric motor failure.

2. *Mikron and Land Portable Infrared Thermometers.* Both units remotely measure the temperature of any surface from up to a distance of 18 ft (5.5 m). The Mikron unit is a direct-read and recording device, while the Land unit is direct-read with a separate datalogger.

3. *Quantum Instruments Gas Leak Probe.* Detects and locates the source of combustible gas leaks. It is a stand-alone palm-sized instrument that alerts the user with an audio signal.

4. *Metrix Vibration Meter.* Measures vibration displacement and velocity on vibrating surfaces. It is a stand-alone hand-held range-selection device.

5. *Hellige Colorimeter.* Analyzes water samples for various chemical substances. It is a portable unit that requires the inspector to collect water samples.

A summary of the basic features of all these instruments is provided in Table 1.

Applications for Selected Instrumentation

The most appropriate applications for the 14 systems evaluated in this research generally fell into eight inspection categories:

1. Heating, ventilating, and air conditioning (HVAC) systems
2. Rotary motors
3. Protective coatings
4. Concrete structures
5. Masonry and mortar structures
6. Wood structures

7. Metals and connections
8. Electrical distribution systems.

Appendix E includes more information about the types of inspection tasks the systems may be used for, the sampling method employed, and how the system is used in each application.

Results of Field Evaluations

Each participating installation and lab rated the applicability of the systems it field-tested as A (fully applicable), B (applicable with some reservations), or C (applicable with significant reservations). The results of these ratings are compiled in Table 2.

Continuing Studies and Support for QA Instrumentation

As noted previously, continuing field evaluations are planned with other Army installations whose DEHs have indicated an interest in using S/M systems to enhance the effectiveness of QA inspections.

One product of this research is the development of a "lending library," or equipment bank, of S/M instrumentation for use by DEHs. USACERL has proposed the equipment bank so DEHs may first try the most potentially useful systems before buying them. Furthermore, since a number of the systems evaluated in this research may be needed only one or two times a year on an average installation, the USACERL S/M equipment bank may offer DEHs regular access to some of the more advanced systems without requiring them to invest the considerable amount of money that it would cost to own them.

An effort connected to the operation of the equipment bank is the publication of a catalog detailing the specifications and specific applications for each S/M system (Johnson, James H., *Catalog of Industrial Instrumentation for Army Real Property Quality Assurance Applications*, Draft Special Report [SR] FF-94/DRAFT [USACERL, 1993]). The publication will offer DEH personnel a convenient reference dedicated exclusively to S/M applications for installation QA activities.

Table 1

Basic Features of Tested Instrumentation

	Device	Output	Power	Portability	Sensor	Data Recording Method
1.	Tooke Mark IV	A direct microscale measure	N/A	Leather case	None	Manual record of magnified observations & thicknesses.
2.	Solomat System (Multiple probes)	Direct & recorded readouts	Probes: IB+ Data Log: Chgr & B+ Pack	Hard case (1'X 2')	All HVAC type measures	Separate data logger which can be downloaded to central PC.
3.	Positector Gage	Direct numerical readout	Internal bat. (IB+)	Palm-size SC* unit	Magnetic field disp.	Manual record of direct readouts.
4.	Amprobe CT-23 Tracer & Freq. Generator Units	Flashing lights & faint audio of the Tracer	IB+ and tested circ sources	Two palm size SC units	Elect freq meter	Label the traced wires as they are identified.
5.	Hanna Field pH/Temp Probe	Direct digital readout (DDR)	IB+	Small (6")	H+ ion level & Temp measures	Manual record of numerical pH (acidity/alkalinity) readings.
6.	Kernco BECI 54A11	Good/Marg/Bad readings	IB+	Hand-held SC unit	Accelerometer	Manual record of bearing status, a qualitative indicator only.
7.	TIF Halogen Leak Detector	Audible alarm	IB+	Hand-held SC unit	Detection of Ha by chem. reaction	Manual record of leak detection & location (not always sensitive to faint leak sources.)
8.	Amprobe Supersonic Leak Detection Sys. ULD 200 Detector UT-200 SS Gener.	Audible sound gen prop to detected SS sound	IB+	Two palm-size SC units	Detection of high freq. pres. waves	Manual record of leak detection & location. (Fine leaks can be detected.)
9.	Walker Gausmeter	DDR	IB+	Hand-held SC unit	Detects magnetic-field (Hall-effect)	Manual record of position, orientation, and DDR of unit.

*SC: self-contained.

Table 1 (Cont'd)

	Device	Output	Power	Portability	Sensor	Data Recording Method
10.	Mikron IR Temp Device	Meter dial	IB+	Hand-held scope	Measures IR energy from target source	Manual records only.
11.	Land IR Temp System	DDR & data transmittal link	Rechargable B+ Pack	Hand-held camera-type; data-logger	Measures IR energy from target source	All measurements recorded by a separate data-logger for downloading into PC for further SW.
12.	Quantrum Gas Leak Probe	Audible clicking sound; rate is prop to gas concentration.	IB+	Palm-size SC unit	Detects oxidation of the comb gas	Manual record of combustible gas presence & its relative strength.
13.	Metrix Vibration Meter	Direct readings which must be interpreted	IB+	Hand-held meter with proble attach.	Detects ampl/freq of vertical & horiz. vibrations	Manual record of motor vibration at prescribed locations.
14.	Hellige Colorimeter	DDR of water sample and distilled water (for calibration).	IB+	Bench area required	Sends light beam thru reagent doctored water; trans properties relate to impurity concentration	Chem lab techniques required for measuremens; water samples may be collected by inspectors.

Table 2

Results of Field Evaluations

	Fort Meade	Fort Monmouth	Fort Ritchie	USACERL	USACRREL
Tooke Mark IV Coating Thickness Gage	A		A	A	A
Solomat 2000 and 2016	A		A	A	A
Positector Coating Thickness Gage	A	A	A	A	A
Amprobe CT-23 Current Tracer		B		B	B
Hanna pH/Temp Probe	B	B			B
Kemco BECI 54A11	C			C	C
TIF Halogen Leak Detector	B		B	B	B
Amprobe ULD-200	B			B	B
Amprobe UT-200	B			B	
Walker Gaussmeter				C	C
IR Thermometers				A	B
Quantum Gas Leak Probe		A		A	A
Metrix Vibrator Meter				A	
Hellige Color Meter				B	

Grades: A = completely applicable to QA needs; B = applicable with some reservations about the tested instrument; C = applicable with significant reservations about the tested instrument.

4 SUMMARY

As the Army downsizes and is required to fulfill its mission with lower operating budgets and less experienced technical personneld, QA activities are significantly affected. One way to help meet the rigorous QA demands posed by the realities of the modern Army and changing technology is through new applications of S/M systems. Such systems, in conjunction with data monitoring and analysis tools, are expected to enhance the observations and judgments of the less experienced inspector.

In general, the most potentially useful QA applications for S/M systems are in the areas of utilities and buildings. Potential S/M inspection applications for utilities exist in the areas of water, sewage, gas, electric, heating, and cooling services. Potential applications for buildings include the areas of electrical, plumbing, metal, carpentry, masonry, concrete, painting, gutters, and drainage work.

The most appropriate applications for the 14 systems evaluated in this research generally fell into the categories of HVAC, rotary motors, coatings, structures (concrete, masonry, mortar, and wood), and metal connections.

The installation DEHs and laboratories that evaluated the first 14 S/M systems acquired by USACERL found in general that most of the systems were applicable to appropriate Army QA activities with few or no reservations. The systems acquired by USACERL have been used to start an equipment bank, which will make these systems available to interested DEHs for evaluation or periodic QA work. Further field evaluations are planned at other test sites, and it is expected that new systems and applications will be investigated in the future.

APPENDIX A: DEH Inspection M&R Responsibilities

Building and Grounds (B&G) Division

B&G manages the maintenance, repair, and improvement of the installation's buildings, structures, roads, railroads, hardstands, airfields, and grounds. It provides custodial and pest-control services, and manages the forestry, fish and wildlife, land management, self-help, and preventive maintenance programs.

Buildings and Structures Branch

1. Wood Structures and Carpentry
2. Reinforced and Precast Concrete Structures
3. Masonry Structures
4. Foundation Systems
5. Painting
6. Roofing Systems
7. Drainage Systems
8. Indoor Air Quality
9. Indoor Water Quality
10. Custodial Services
11. Building Pest Control Service

Land Management Branch

1. Lawn Fertilization
2. Weed Control Services
3. Pest Control Services
4. Soil Subsurface Investigation
5. Outdoor Paved Surfaces
6. Outdoor Air Quality
7. Outdoor Water Quality
8. Snow Removal /Ice Control
9. Policing and Security

Roads and Railroads Branch

1. Paved Roads, Driveways, and Parking Lots
2. Airfields
3. Railroads
4. Bridges

Engineer Resource Management Division (ERMD)

1. Work Order Reception Office/Desk
2. Work Order Flow Management
3. SO/IJO Recordkeeping

Utilities Division

This division manages the operation, maintenance, repair, and minor construction of the installation's utility plants and systems, provides refuse and solid waste collection services, and administers utilities contracts within delegated authorities.

HVAC Systems, Mechanical Branch

1. Heating Systems
2. Ventilation Systems
3. Air Conditioning Systems
4. HVAC Pumps, Motors, Compressors, and Fans

Refrigeration Systems

Electrical Branch

1. Electrical Supply Stations
2. Electrical Distribution
3. Lighting Systems
4. Telephone / Telecommunication Distribution
5. Computer Network Distribution

Sanitation Branch

1. Water Supply and Distribution
2. Water Treatment / Sanitation Systems
3. Sewage Collection and Treatment Systems
4. Refuse and Solid Waste Disposal
5. Recycling Waste

Energy Branch

Other Divisions (not included in this study)

1. Engineering Planning and Services (EP&S) Division
2. Environmental and Natural Resource Division
3. Housing Division

APPENDIX B: Field Survey of Potential QA Instrumentation Test Sites

[SAMPLE LETTER]

SUBJECT: EVALUATION OF FIELD-PORTABLE QA MEASUREMENT/DETECTION DEVICES FOR SUPPORT OF INSPECTION-RELATED ACTIVITIES

DATE: 20 MARCH 1993

1. USACERL is currently evaluating field-portable, commercially-available intelligent sensor/measurement devices for supporting Quality Assurance (QA) inspection activities. This evaluation will be performed between 1 April and 1 July 1993. We wish to determine if intelligent inspection equipment can improve the accuracy and reproducibility of inspection results as well as improve the timeliness and effectiveness of the data captured.

2. Attached is a list of QA equipment to be made available from USACERL to any requesting DEH on a time-limited loan basis. The list identifies the supplier and describes the functional uses of each of the supplied systems. Also attached is a one-page reply form. It is requested that you support our inquiry by completing this form and returning it in the pre-addressed envelope provided.

3. For any questions or concerns regarding this inquiry, feel free to contact USACERL POCs: James Johnson (Principal Investigator) or Marc Poskin (Associate Investigator) at (217) 352-6511 or (800) USA-CERL. A prompt reply will be greatly appreciated.

REPLY FORM

INSTRUCTIONS:

1. Please review the equipment descriptions in the "List of Commercially-Available Field-Portable Maintenance Inspection Devices" (USACERL, 1 March 1991) attached.

2. Check off the maintenance services you feel are of importance to your existing or planned inspection/maintenance needs.

3. Insert the completed reply form into the pre-addressed envelope and mail by 31 March 1993.

MAINTENANCE SERVICES:

1. FACILITY STRUCTURAL DETERIORATION _____
2. PLANTS AND EQUIPMENT STATUS _____
3. UTILITIES GENERATION _____
4. UTILITIES DISTRIBUTION _____
5. HABITABILITY STANDARDS _____
6. MECHANICAL SYSTEM ASSESSMENTS _____
7. ROTARY MOTOR MEASUREMENTS _____
8. VISUAL INSPECTION AIDS _____
9. INFRARED INSPECTION SYSTEMS _____
10. LEAK DETECTION SYSTEMS _____
11. PROTECTIVE FINISH ASSESSMENTS _____

If inspection devices related to the areas of service you checked off on this attachment were provided to your installation on a 15-day rent-free basis, would you be interested in participating in a CERL-supported user/performance evaluation program for this selected equipment?

YES _____ NO _____

Please list inspection-related equipment that your office currently uses or plans to purchase.

_____

_____

_____

INSTALLATION(S) SUPPORTED: _____

NAME/ORGANIZATION: _____

APPENDIX C: Identification of Potential Inspection Applications

Utility

Water Services

1. Locate leaks, cracks, holes, or other anomalies in water pump casings, water lines, and water storage tanks.

2. Locate underground water utility lines and water storage tanks without digging or disturbing the soil.

3. Inspect water, sewer, and steam distribution lines to locate internal surface anomalies including cracks, holes, corrosion, build up, and pipe blockage.

4. Perform routine preventive maintenance on water, sewer, or steam lines.

5. Verify and monitor required differential and gauge supply pressures within hot and cold water supply and distribution systems.

6. Measure the thickness of oxidation buildup in water storage tanks.

7. Locate and measure stress vibrations in piping systems.

8. Monitor and measure corrosion in water and steam piping.

9. Monitor and measure calcium buildup in storm, water, and sewer drainage piping.

10. Monitor Ph levels in plant and operations water supplies.

11. Analyze water samples in water and sewage treatment plants at different stages of the filtering process.

12. Monitor chlorine and pH levels in swimming pools.

13. Test feed and cooling water preparation for calcium content in boilers, chillers, heat exchangers.

14. Test drinking water for lead, fluoride, calcium, etc., from supply areas and other locations (e.g., sinks, drinking fountains) in buildings with older plumbing systems.

15. Test water used for watering grass, plants, and building grounds from sprinklers and hoses.

Sewage Services

1. Detect, monitor, and measure methane gas concentrations in sewage treatment plants and underground facilities.

2. Analyze water samples in water and sewage treatment plants at different stages of the filtering process.

3. Test for effluent control, pollution, and discharge.

Gas Services

1. Detect leaks of combustible gases in storage facilities, distribution areas, and at connection points.

2. Locate and detect gas or liquid leaks from underground storage tanks or distribution lines, and measure any resulting soil contamination.

3. Detect POL leaks in storage, under transport, or during loading and unloading.

4. Detect propane fuel leaks in containment and distribution areas.

5. Detect refrigerant gas leaks.

6. Detect and locate leaks in any enclosed fuel or refrigerant circulatory system.

7. Locate leaks, cracks, holes, or other anomalies in fuel pump casings and lines, refrigeration systems, and gas engines.

8. Locate underground fuel storage tanks or distribution lines without digging or disturbing the soil.

Electric Services

1. Identify overheated circuit breaker and switch gear boxes, transformers, transmission lines, and other electrical supply and distribution interfaces.

2. Detect overheated fluorescent ballasts, lamps, and conduit or exterior lighting systems.

3. Detect and monitor interference caused by high magnetic flux outputs from high-voltage areas, power plants, transmission lines, transformers, and generators.

4. Measure magnetic flux density around electric motors as a predictive maintenance tool for detecting signs of wear and potential failure.

5. Verify that storage areas for sensitive materials such as photographic film, computer software media, and magnetic tape are free from high levels of magnetic flux.

6. Check power surges and fluctuations in sensitive electronic equipment, including computer, microwave, radio, and satellite systems.

7. Inspect power generation plants, transformers, conduit cable pipes and trays, and steam generators for corrosion or obstructions.

Heating Services

1. Locate and detect overheated steam traps in steam distribution equipment.

2. Detect areas of heat loss in heat and steam generation plants.

3. Provide routine scheduled maintenance checks on the operations of boilers, pipes, heat exchangers, and other hot air, water, and steam distribution equipment.

4. Detect overheated pumps, motors, compressors, and generators.

5. Monitor vibration levels and detect degradation trends in fuel-powered or electric motors, and other rotary systems such as pumps, compressors, and generators.

6. Support acceptance and installation checks on new equipment with shaft and vibration measurements that may indicate shaft misalignment, mounting errors, faulty or missing bearings and gaskets, improper tension in belts and chains, etc.

7. Detect and quantify excessive vibration levels in HVAC distribution equipment, blowers, fans, grilles, and ducts.

8. Verify specified thickness levels for equipment acceptance and specification checks on galvanizing, metallizing, plating, or phosphating on steel for pumps, motors, water heaters, etc.

9. Measure rotational speeds of gears, motors, belts, fans, and pulleys in a preventive maintenance program; use inductive probes to count gear teeth without shutting down machinery.

10. Measure air pressure for monitoring air filter efficiencies in HVAC heating systems.

11. Monitor compressed air and steam lines to check pressure fluctuations.

12. Monitor and measure contaminants in oil, hydraulic fluid, or other fluids caused by dirty filters in HVAC power and distribution equipment.

13. Monitor air speeds and flows through HVAC distribution equipment, fans, blowers, and ventilation systems.

14. Monitor and record air flow to furnaces, boilers, and incinerators for operating and preventive maintenance purposes.

15. Monitor, measure, and record carbon monoxide and oxygen levels emitted from furnaces, heat exchangers, boilers, or ovens to assure the highest-efficiency output, and ensure that specified safety limits are not exceeded.

16. Visually inspect the cavities of pumps, compressors, heat exchanger tubing, turbine blades, and combustion chambers.

17. Perform borescope acceptance and installation checks on new equipment for missing bearings, improper mounting, weld integrity, loose gaskets, screws, or any other hard-to-find problems.

Cooling Services

1. Monitor humidity and temperature in sensitive environments such as computer rooms, storage facilities, clean rooms, or laboratories.

2. Detect overheated pumps, motors, compressors, and generators.

3. Monitor vibration levels and detect degradation trends in fuel-powered electric motors or other rotary systems, including pumps, compressors, and generators.

4. Support acceptance and installation checks on new equipment with shaft and vibration measurements that may indicate shaft misalignment, mounting errors, faulty bearings or gaskets, improper tension in belts and chains, etc.

5. Detect and quantify excessive vibration levels in HVAC distribution equipment, blowers, fans, grilles, and ducts.

6. Verify specified thickness levels for equipment acceptance and specification checks on galvanizing, metallizing, plating, or phosphating on steel for pumps, motors, water coolers, etc.

7. Measure rotational speeds of gears, motors, belts, fans, and pulleys in a preventive maintenance program; use inductive probes to count gear teeth without shutting down machinery.

8. Measure air pressure for monitoring air filter efficiencies in HVAC cooling systems.

9. Monitor compressed air and steam lines for checking pressure fluctuations.

10. Monitor and measure contaminants in oil, hydraulic fluid, or other fluids caused by clogged or dirty filters in HVAC power and distribution equipment.

11. Monitor air speeds and flows through HVAC distribution equipment, fans, blowers, and ventilation systems.

12. Monitor dewpoint levels in HVAC equipment, refrigeration systems, coolers, and chillers for preventive maintenance activities.

13. Monitor cooling water and other circulatory fluid temperatures.

14. Perform borescope acceptance and installation checks on new equipment for missing bearings, improper mounting, weld integrity, loose gaskets, screws, or any other hard-to-find problems.

Building Operations and Maintenance

Electrical Work

1. Visually inspect wall, floor, and ceiling cavities for structural integrity, mechanical system remodeling or rerouting, moisture damage, presence of insulation, or for locating studs or other obstructions.

2. Detect overheated fluorescent ballasts, lamps, and conduit or exterior lighting systems.

3. Check power surges and fluctuations in sensitive electronic equipment, including computer, microwave, radio, and satellite systems.

4. Verify that storage areas for sensitive materials such as photographic film, computer software media, magnetic tape, etc., are free from high levels of magnetic flux.

Plumbing Work

1. Locate and measure stress vibrations in piping systems.

2. Measure and monitor corrosion or calcium buildup in piping systems.

Metal Work

1. Measure the thickness of corrosion in metal pipes, tanks, and fixtures.

2. Measure corrosion on structural and exterior metal fabrications in corrosive environments, including stairs, handrails, scaffolding, and other structural supports subject to corrosion.

3. Determine the number of coats of paint on any conductive substrate, such as metal stairs, handrails, exterior metal panels, gutters, metal windows, awning frames, and any paintable metal surface that is part of a building.

4. Verify anodizing layer on aluminum gutters, siding, window/door frames, or other exterior building elements.

Carpentry Work

1. Locate the presence (or lack) of insulation in walls, floors, ceilings, and roofs.

2. Detect areas of heat loss or moisture-damaged insulation in walls, floors, ceilings, and roofs.

3. Detect drafts and monitor heat loss through walls, windows, doors, openings, etc.

Masonry and Concrete Work

1. Measure the thickness of cured concrete, either in slab or panel form.

2. Determine when concrete has reached a specified strength, measure its moisture content, or locate areas of void or trapped moisture within recently poured concrete.

3. Locate the presence (or lack) of insulation in walls, floors, ceilings, and roofs.

4. Detect areas of heat loss, cracked masonry, or moisture-damaged insulation in walls, floors, ceilings, and roofs.

Painting Work

1. Measure the amount of lead in painted surfaces and in unused paint.

2. Determine the thickness of paint on any metal substrate.

Gutters and Drainage Systems

1. Visually inspect behind concrete, aluminum, or steel building facade panels (or other exterior enclosure systems) for sources of moisture damage or failing connections.

2. Measure the thickness of paint and anodizing on aluminum gutters and downspouts for specification checks.

APPENDIX D: Suppliers Studied in This Research

The following companies were contacted or studied in this USACERL research. This list is not intended to serve as an exhaustive directory of all S/M system vendors, and it does not necessarily indicate USACERL's preferred sources for these instrumentation systems; it shows which vendors came to the authors' attention by way of catalogs, listings in industry directories, and background knowledge of the technology.

1. AF Infrared
2608 West Lincoln Highway
Merrillville, IN. 46410
(Tel.) 219-736-0202

2. Amprobe Instrument
630 Merrick Road, PO Box 329
Lynbrook, NY. 11563
(Tel.) 516-593-5600

3. DeFelsko, Inc.
410 Cedar Street
Ogdensberg, NY. 13669
(Tel.) 1-800-267-0607

4. Emco Sales and Distribution
88 Bartley Road
Flanders, NJ. 07836
(Tel.) 201-927-2900

5. Flir Systems, Inc.
16505 SW 72nd Avenue
Portland, OR. 97224
(Tel.) 503-684-3731

6. Heath Consultants, Inc.
1809 Riley Road
New Castle, IN. 47362
(Tel.) 317-521-2068

7. Inframetrics, Inc.
12 Oak Park Drive
Bedford, MA. 01730
(Tel.) 508-670-5555

8. Instruments Technology
P.O. Box 381
Westfield, MA. 01086
(Tel.) 413-562-3606

9. IRD Mechanalysis
6150 Huntley Road
Columbus, OH. 43229-1074
(Tel.) 614-885-53769

10. James Instruments, Inc.
3727 Kedzie Avenue
Chicago, Illinois 60618
(Tel.) 800-426-6500

11. Kernco Instruments Company
420 Kenazo Avenue
El Paso, TX. 79927
(Tel.) 800-325-3875

12. KTA-TATOR, Inc.
115 Technology Drive
Pittsburgh, PA. 15275
(Tel.) 412-788-1300

13. Land Infrared
2525 Pearl Buck Road
Bristol, PA. 19007
(Tel.) 215-781-0700

14. Lenox Instrument Company
265 Andrews Road
Trevose, PA. 19053
(Tel.) 215-322-9990

15. Machida, Inc.
40 Ramland Road South
Orangeburg, NY. 10962-2698
(Tel.) 800-431-5420

16. Metrix Instrument Company
1711 Townhurst Drive
Houston, TX. 77043
(Tel.) 713-461-2131

17. Mikron Instruments Company
445 West Main Street
Wyckoff, NJ. 07481
(Tel.) 201-891-7330

18. Nucleus Corporation
25880 Commerce Drive
Madison Heights, MI. 48071
(Tel.) 313-399-3610

19. Olympus Instruments
1800 Sandy Plains Rd, Suite #307
Marietta, GA. 30064
(Tel.) 800-537-1882

20. Optronics Engineering
175 B Cremona Drive
Goleta, CA. 93117
(Tel.) 805-968-3568

21. Orbeco Analytical Systems, Inc.
185 Marine Street
Farmingdale, NY. 11735
(Tel.) 516-293-4110

22. Panametrics, Inc.
221 Crescent Street
Waltham, MA. 02254
(Tel.) 800-225-8330

23. PCB Piezotronics
3425 Walden Avenue
Depew, NY. 14043-2495
(Tel.) 716-684-0001

24. Princeton Gamma-Tech, Inc.
568 Weddell Drive, Suite #1
Sunnyvale CA. 94089
(Tel.) 408-734-8124

25. Quantum Instruments Inc.
1075 Stewart Avenue
Garden City, NY. 11530
(Tel.) 516-222-0611

26. Raytek, Inc.
1201 Shaffer Road, Box 1820
Santa Cruz, CA. 95061-1820
(Tel.) 800-227-8074

27. Savi Technology, Inc.
350 Cambridge Avenue, Suite #50
Palo Alto, CA. 94306
(Tel.) 415-328-4323

28. Sharples Stress Engineers, Ltd.
Preston, Lancashire, U. K.

29. Solomat Instrumentation Division
652 Glenbrook Road
Stamford, CT. 06906
(Tel.) 800-932-4500

30. Spatial Dynamics Applications
42 Washington Drive
Acton, MA. 01720
(Tel.) 508-263-7704

31. Spectronics Corporation
956 Brush Hollow Road, POB 483
Westbury, NY. 11590
(Tel.) 800-274-8888

32. TEC
PO Box 22996, Lexington Drive
Knoxville, TN. 37933-0996
(Tel.) 615-675-1241

33. Telatemp Corporation
PO Box 5160
Fullerton, CA. 92635-0160
(Tel.) 800-321-5160

34. TIF Instruments, Inc.
9101 NW 7th Avenue
Miami, FLA. 33150
(Tel.) 305-757-8811

35. TSI Incorporated
PO Box 64394
St. Paul, MN. 55164
(Tel.) 612-490-2807

36. UE Systems
12 West Main Street
Elmsford, NY. 10523
(Tel.) 800-223-1325

37. Walker Scientific, Inc.
Rockdale Street
Worcester, MA. 01606
(Tel.) 508-852-3674

38. Welch Allyn Video Division
4341 State Street Road
PO Box 220
Skaneateles Falls, NY. 13153
(Tel.) 315-685-4100

APPENDIX E: S/M Systems Evaluated by Army Users

Tables E1 through E7 list the S/M systems evaluated for seven different DEH task areas. The manufacturer reference numbers in Column 4 are keyed to the suppliers listed in Appendix D.

Most systems evaluated require no training beyond consulting the manufacturer's instructions. In Column 5 of the tables, it is noted that advanced skills may be required to use a device or interpret its data. In these cases, depending on the user's background and experience, additional training may be required.

Table E1

Heating, Ventilating, and Air Conditioning (HVAC) Systems

PERFORMANCE REQUIREMENTS	ACCEPTABLE NDE METHOD	INSTRUMENTATION INVESTIGATED	MFR. REF. NO.*	DESCRIPTION OF OPERATION AND LEVEL OF USER EXPERTISE REQUIRED
1. Proper air flow	Hot-Wire Anemometer	Solomat MPM 2000 w/ hot-wire probe	29	A thermistor sensor monitors the cooling down effect caused from air passing by a very fine heated wire. The amount by which the hot wire is cooled is directly proportional to the air speed. With the Solomat microprocessor, a direct readout of air speed is obtained. Moderate skill level is required to make measurements and interpret readings.
	Vane Anemometer	Kemco Digital Vane Anemometer Model 20D13	11	The rotational speed of a 3" propeller is taken as directly proportional to the air speed. A built-in microprocessor provides a digital readout of the air speed in feet per minute. Moderate skill level is required to make measurements and interpret results.
2. Proper air temperature	Platinum RTD (Resistance Temp. Detector)	Solomat MPM 2000 w/ thermo-hygro probe	29	Based on the principle of resistance temperature, a 100 ohm platinum disk is electrically charged. As air passes across the disk, the electrical resistance of the platinum is measured and is inversely proportional to the air temperature. With the Solomat microprocessor, a direct readout of temperature in Fahrenheit or Celsius is provided. Low skill level required to make measurements and interpret readings.
3. Relative humidity	Electrical Capacitance	Solomat MPM 2000 w/ thermo-hygro probe	29	A thin polymer and bronze film sensor responds to water vapor in the air. The amount of water vapor on the film sensor affects the electrical capacitance of the bronze capacitor. The amount of change in electrical capacitance is inversely proportional to the relative humidity of the air. With the Solomat microprocessor, a direct digital readout of percentage relative humidity is provided. Low skill level required to make measurements and interpret readings.
4. Properly sealed air ducts	Ultrasonic	Amprobe Ultrasonic Leak Detector	2	When any pressurized gas, steam, or water vapor passes through a small opening greater than 10 (-5) ML/sec., ultrasound sound is created. Since ultrasonic sound is any sound above 20 kHz in frequency, it cannot be heard by the human ear. The Amprobe ULD-100 converts this "silent" sound into a frequency 32 times lower, creating an audible sound. Low skill level required to operate, but expertise needed to "home-in" on source of leak.

*** Refer to Appendix D for information on suppliers.**

Table E1 (cont'd)

PERFORMANCE REQUIREMENTS	ACCEPTABLE NDE METHOD	INSTRUMENTATION INVESTIGATED	MFR. REF. NO.*	DESCRIPTION OF OPERATION AND LEVEL OF USER EXPERTISE REQUIRED
4. Properly sealed air ducts	IR Temperature	Mikron Portable Infrared Thermometer	17	Measures electromagnetic radiation generated by any material. Based on the principle of the thermistor bolometer, two matched metal elements—one exposed to the source of radiation, the other shielded are connected in a bridge circuit where an electrical potential is realized. The measure of electrical potential is proportional to amount of radiation energy on the exposed element. A direct scaled temperature in (°F and °C) is provided. When scanning the HVAC supply duct through a sighting device, temperature changes can indicate leaks. Low to moderate skill level required to operate and interpret readings.
5. Presence of halogen or freon leaks	Ultraviolet Light Fluorescent Dye	Spectroline Fluorescent** Leak Detection System	31	A fluorescent dye is added to the AC freon system through a mist infuser attached to the test manifold. The fluorescent dye mixes with the freon and is given time to circulate through the compressors, valves, coils, and tubing. A hand-held, high-intensity ultraviolet lamp is then shone over these surface; minute leaks are identified by a bright yellow-green glow. Low skill sufficient for operation and interpretation.
	Electrical Capacitance	TIF 5000 Halogen Leak Detector	34	Air passes through a nonconducting liquid film. If halogen gas is present, it is absorbed onto the film and an electrical current passes through the film. A semipermeable membrane, wrapped around an electrode, accepts only halogen ions to the negative pole cathode. The conductance created is an indication of the halogen gas present. Low skill level sufficient for operation; experience is required to pinpoint leak sources.
6. Presence of combustible gas leaks	Combustion	Quantum Instruments Gas Leak Probe	25	An internal ceramic heater burns minute levels of any combustible gas present in the air. The rise is temperature within the ceramic heater triggers the change in electrical capacitance of a capacitor. Change in capacitance increases the beeping rate of the audible alarm from a "normal" rate to a very fast rate, indicating the presence of a combustible gas. Low skill level sufficient for operation and interpretation of the alarm's beeping rate.
7. Combustion efficiency	Oxygen, Temp., Carbon Monoxide Levels	Kemco Combustion Efficiency Analyzer Model 48A12	11	Because thermal efficiency is related to excess oxygen in flue gasses, oxygen is measured with a fuel sensor and built-in thermocouple for temperature measurement. The amount of oxygen in the flue in relation to its temperature, can provide an indication of thermal efficiency. Moderate skill level required to operate; expertise reauired to interpret results.

*** Refer to Appendix D for information on suppliers.**

**** Demonstrated by contractor for DEH Worldwide Training Conference, 8 December 1991, Dallas, TX.**

Table E2

Rotary Motors

PERFORMANCE REQUIREMENT	ACCEPTABLE NDE METHODS	INSTRUMENTATION INVESTIGATED	MFR. REF. NO.*	DESCRIPTION OF OPERATION AND LEVEL OF USER EXPERTISE REQUIRED
1. Bearing condition	Accelerometer	Vitec Bearing Condition Indicator (BECI)	11	A quartz crystal accelerometer attached to a reference mass produces a voltage when compressed by the movement of the reference mass. The voltage is proportional to the amplitude of the oscillation caused from the applied vibrating mass. A special internal quartz accelerometer detects these high frequency vibrations while ignoring normal machine vibrations. A direct needle readout on a simple 1-5 scale indicates relative bearing condition. Low skill sufficient for operation and interpretation.
	Quartz Transducer (Shock Pulse Method)	Kemco Bearing Analyzer BEA-53	11	A piezoelectric quartz crystal attached to a reference mass produces a voltage when compressed by the movement of the reference mass. The voltage is proportional to the amplitude of the oscillation and to the shock wave created by the roller bearing compressing the bearing raceway. Shock pulse meters are mechanically tuned to operate at only a frequency of 32 kHz, thereby ignoring normal machine vibrations. Output is signaled in decibels (dB), either digitally displayed or acoustically emitted through headphones. Low skill sufficient for operation; expertise required for interpretation especially in the tone generation mode where the user listens to shock pulse patterns emitted by bearings.
2. Motor vibration	Accelerometer	Metrix Vibration Meter Model 5160DV	16	A piezoelectric quartz crystal attached to a reference mass produces a voltage when compressed by the movement of the reference mass. The voltage is proportional to the amplitude of the oscillation of the reference mass caused from the applied vibration. The signal is conditioned for both velocity and displacement readings on an integral hand held enclosure where the probe, pickup, signal conditioner, and meter are all contained. Low skill level sufficient for operation and interpretation of readings.

*** Refer to Appendix D for information on suppliers.**

Table E2 (cont'd)

PERFORMANCE REQUIREMENT	ACCEPTABLE NDE METHOD	INSTRUMENTATION INVESTIGATED	MFR. REF. NO.*	DESCRIPTION OF OPERATION AND LEVEL OF USER EXPERTISE REQUIRED
3. Shaft alignment	Accelerometer	Metrix Vibration Meter Model 5160DV w/ Shaft Rider Fork Attachment	16	A specially designed shaft rider fork, attached to the Metrix vibration meter, rests on a rotating shaft. Shaft misalignment results in levels of vibration proportional to the speed of the shaft. Low skill level sufficient for operation and interpretation.
	Thermography	Agema Thermovision 470 IR Imaging System	1	Infrared (IR) radiation is produced by any object having a temperature above absolute zero (-273 °C). Infrared is electromagnetic radiation with a wavelength ranging between 0.75 and 1,000 micrometers, thereby making it not visible to the human eye. Thermographic imagers use quantum detectors which convert invisible IR radiation to a voltage signal which in turn can produce thermographic pictures for viewing on a television-like display. IR imagers can identify "hot spots" on operating machinery. Low skill level sufficient for operation; considerable expertise required to interpret images, unless enhanced by a color graphics software program.
4. Magnetic flux (density) output	Electrical Voltage (Hall Drift Effect)	Walker Scientific Gaussmeter Model MG-4D	37	Measures magnetic field densities around electrically-powered equipment. A flat chip conductor in the probe produces a small horizontal current. When a magnetic field passes perpendicular through this chip, a Hall drift current is produced. The Hall voltage is then measured and scaled to read directly in gauss units. A history of readings must be kept; unusually high readings indicate potential motor problems. Moderate skill required to operate; considerable expertise required to interpret readings.

*** Refer to Appendix D for information on suppliers.**

Table E3

Protective Coatings

PROPERTY	ACCEPTABLE NDE METHOD	INSTRUMENTATION INVESTIGATED	MFR. REF. NO.	DESCRIPTION OF OPERATION AND LEVEL OF USER EXPERTISE REQUIRED
1. Number and type of coatings	Visual / Microscope	Tooke Gage Mark IV	12	A beveled cutting edge scribes a small v-grooved incision into the protective coating down to the substrate. Visual examination is made through an illuminated 10X power microscope with an equipped reticle (scale) in the eyepieces to measure the number and thickness of protective layers. Low skill level is sufficient for use and interpretation.* Refer to Appendix D for information on suppliers.
2. Thickness (on ferrous base)	Magnetic Field	Positector 2000 Coating Thickness Gage	11	A ruby-tipped probe connects to a core magnet inside an energized electric coil with a balancing magnetic field strength. The more coatings covering the ferrous substrate (ie. the further the core magnet is from the substrate), the more imbalanced the total field becomes. The magnetic field strength's imbalance is proportional to the coating thickness. No calibration required; very easy to use. Low skill level is sufficient for operation and interpretation.
3. Thickness (on ferrous and nonferrous base)	Eddy Current	Electrometer 256 Microprocessor	12	An electrically excited coil induces an eddy current (against the main flow) and an associated electromagnetic field into the metal substrate. Flaws, anomalies, and coatings alter the impedance of the excitation coil. Changes in the coil impedance are proportional to coating thickness. Moderate skill level is sufficient to operate and understand readings.
4. Thickness (on all surfaces)	Visual / Microscope	Tooke Gage Mark IV	12	Microscope eyepiece equipped with scaled graduation tick marks allows user to measure coating thicknesses of various films. See Property #1 for method description.

*** Refer to Appendix D for information on suppliers.**

Table E4

Concrete Structures

PROPERTY	ACCEPTABLE NDE METHOD	INSTRUMENTATION INVESTIGATED	MFR. REF. NO.*	DESCRIPTION OF OPERATION AND LEVEL OF USER EXPERTISE REQUIRED
1. Quality, uniformity, durability	Utrasonic Pulse Velocity	V-Meter	10	Ultrasonic energy is pulsed through a concrete sample; the velocity of the pulse is measured and is proportional to the density and elastic properties of teh concrete. Separate transmitting and receiving transducers are required. Low skill level sufficient for making measurements; expertise required for assessing quality.
	Microwave	Spatial Dynamics M600 Concrete and Cement Tester	30	Patented antenna emits low-level microwave energy into the concrete; measures the dielectric properties by comparing the signal it produces with the reflected signal. High level of expertise required to interpret the results.
2. Thickness	Microwave	Spatial Dynamics M600 Concrete and Cement	30	Patented hand-held antenna emits low-level microwave energy into the concrete; measures the dielectric properties by comparing the signal it produces with the reflected signal. High level of expertise required to interpret the results.
	Ultrasonic Echo Pulse	E-Meter	10	Pulsed compressional waves are induced into the concrete; those reflected back into the receiving transducer are detected and their strength measured. One probe contains both transmitting and receiving transducers. High level of expertise required to interpret the results.
3. Moisture content	Microwave	Spatial Dynamics M600 Concrete and Cement Tester	30	Patented hand-held antenna emits low-level microwave energy into the concrete; measures the dielectric properties by comparing the signal it produces with the reflected signal. Low reflection readings can indicate absorption areas caused by moisture. High level of expertise required to interpret the results.

*** Refer to Appendix D for information on suppliers.**

**** Demonstrated by manufacturer to USACERL requestors.**

Table E4 (cont'd)

PROPERTY	ACCEPTABLE NDE METHOD	INSTRUMENTATION INVESTIGATED	MFR. REF. NO.	DESCRIPTION OF OPERATION AND LEVEL OF USER EXPERTISE REQUIRED
4. Permeability	Magnetic Field	HR-Rebar Locator	10	Presence of steel affects the magnetic field induced by the probe. The closer the probe is to the imbedded steel, the greater the effect. Identifies the size, position, and depth of imbedded rebar. Moderate skill required to interpret the readings.
6. Corrosion state of reinforcement bar			10	A silver chloride half-cell is connected to an exposed section of rebar and to a water-saturated Delrin wheel to complete the circuit. The wheel rolls along the concrete surface parallel to the imbedded rebar; the potential difference between the electrode of the half-cell and the rebar is related to the probability of corrosion of the imbedded rebar. Moderate skill is required to recognize potential differences.
7. Presence of subsurface voids and delaminations			23	Concrete surface is struck with metallic hammer; the frequency and damping characteristics of the "ringing" can indicate the presence of internal defects. Low skill sufficient to perform, but high expertise needed to interpret results.
	Microwave	Spatial Dynamics M600 Concrete and Cement Tester	30	Patented antenna emits low-level microwave energy into the concrete; measures the dielectric properties by comparing the signal it produces with the reflected signal. Variable readings indicate internal discontinuities. High level of expertise required to interpret the results.
	Ultrasonic Pulse Velocity	V-Meter**	10	Ultrasonic energy is pulsed through a concrete sample; the velocity of the pulse is measured and is inversely proportional to the density and elasticity of the concrete. Variable velocity measurements indicate internal voids or delaminations. Separate transmitting and receiving transducers are required. Moderate skill level is sufficient for operation; expertise required for interpretation.

*** Refer to Appendix D for information on suppliers.**

**** Demonstrated by manufacturer to USACERL.**

Table E5

Masonry and Mortar Structures

PROPERTY	ACCEPTABLE NDE METHOD	INSTRUMENTATION INVESTIGATED	MFR. REF. NO.*	DESCRIPTION OF OPERATION AND LEVEL OF USER EXPERTISE REQUIRED
1. Structural integrity	Microwave	Spatial Dynamics M600 Concrete and Cement Tester	30	Patented antenna emits low-level microwave energy into the masonry; measures the dielectric properties of the material by comparing the signal it produces with the reflected signal. Variable readings indicate internal discontinuities. High level of expertise required to interpret the results.
	Ultrasonic Pulse Velocity	V-Meter	10	Ultrasonic energy is pulsed through a masonry sample; the velocity of the pulse is measured and is inversely proportional to the density and elasticity of the tested material. Variable velocity measurements indicate internal voids or anomalies. Separate transmitting and receiving transducers are required. Moderate skill level required for operation; expertise required for interpretation.
	Visual/Borescope	Machida Borescope**	15	A flexible or rigid bundle of optical and light fibers with attached lens is inserted into a small pre-drilled hole in the masonry permitting visual access of interior cavity. Low skill sufficient for visual operation; expertise required for assessment.
	Visual/Videoscope	Welch Allyn Video Probe 2000***	38	A flexible fiber-optic cable with an attached CCD color camera at the tip produces real-time video images on a high resolution color monitor. Inspection areas can be videotaped. Low skill sufficient for operation; expertise required for assessment.
2. Thickness	Visual/Borescope	Machida Rigid Borescope**	15	A flexible or rigid bundle of optical and light fibers with attached lens is inserted into a small pre-drilled hole in the masonry permitting visual access to determine thickness of interior cavity. Low skill sufficient for operation and assessment.

*** Refer to Appendix D for information on suppliers.**

**** Demonstrated by manufacturer at DEH Worldwide Training Conference, 8 December 1991, Dallas, TX.**

***** Demonstrated by manufacturer at USACPW, Fort Belvoir, VA, to user's group.**

Table E5 (cont'd)

PROPERTY	ACCEPTABLE NDE METHOD	INSTRUMENTATION INVESTIGATED	MFR. REF. NO.*	DESCRIPTION OF OPERATION AND LEVEL OF USER EXPERTISE REQUIRED
2. Thickness (cont'd)	Visual/Videoscope	Welch Allyn Flexible Video Probe 2000**	38	A flexible fiber-optic cable with an attached CCD color camera at the tip produces real-time video images on a high resolution color monitor. Inspection areas can be videotaped and wall thickness determined. Low skill sufficient for operation and assessment.
3. Re-bar size, position, and depth	Magnetic Field	HR-Rebar Locator	10	Presence of steel affects the magnetic field induced by the probe. The closer the probe is to the embedded steel, the greater the effect. Identifies the size, position, and depth of imbedded rebar. Moderate skill required to interpret the readings.material. Photographic film record identifies location and size of imbedded rebar. Licensed and trained personnel required.
4. Condition of inner grout	Ultrasonic Pulse Velocity	V-Meter	10	Ultrasonic energy is pulsed through a masonry sample; the velocity of the pulse is measured and is inversely proportional to the density and elasticity of the tested material. Variable velocity measurements indicate internal voids or anomalies caused from the lack of inner grout. Separate transmitting and receiving transducers are required. Low skill level sufficient for operation; expertise required for interpretation.
	Visual / Videoscope	Welch Allyn Video Probe 2000	38	A flexible fiber-optic cable with an attached CCD color camera at the tip produces real-time video images on a high resolution color monitor. Inspection areas can be videotaped for identifying the presence and condition of inner grout. Moderate skill level required for operation and assessment.
	Visual / Borescope	Machida Rigid Borescope	15	A flexible or rigid bundle of optical and light fibers with attached lens is inserted into a small pre-drilled hole through the masonry grout permitting visual access to determine the condition and presence of inner grout. Moderate skill level required for operation and assessment.

*** Refer to Appendix D for information on suppliers.**

**** Demonstrated by manufacturer at USACPW, Fort Belvoir, VA, to user's group.**

Table E6

Wood Structures

PROPERTY	ACCEPTABLE NDE METHOD	INSTRUMENTATION INVESTIGATEDION	MFR. REF. NO.*	DESCRIPTION OF OPERATION AND LEVEL OF USER EXPERTISE REQUIRED
1. Density	Ultrasonic Pulse Velocity	V-Meter	10	Ultrasonic energy is pulsed through a wood sample; the velocity of the pulse is measured and is inversely proportional to the density and elasticity of the wood tested. Variable velocity measurements indicate internal voids or anomalies caused from decay and/or moisture. Separate transmitting and receiving transducers are required. Low skill level sufficient for operation; expertise required for interpretation.
2. Moisture content	Electrical Capacitance	Moisture Meter	10	Measures the dielectric constant (permittivity) of wood within its magnetic field. The water content of the material read directly in percentage moisture. Moderate skill level required for use and interpretation.
	Microwave	Spatial Dynamics M600 Concrete and Cement Tester	30	Patented antenna emits low-level microwave energy into the wood; measures the dielectric properties of the material by comparing the signal it produces with the reflected signal. Variable readings can indicate internal discontinuities. Calibrations and a high level of expertise required to interpret the results.
3. Adhesive bond condition in laminate wood	Thermography	Agema Thermovision470 IR Imaging System	1	Infrared (IR) radiation is produced by any object having a temperature above absolute zero (-273 C.). Infrared is electromagnetic radiation with a wavelength ranging between 0.75 and 1,000 micrometers, thereby making it not visible to the human eye. Thermographic imagers use quantum detectors which convert invisible IR radiation to a voltage signal which in turn can produce thermographic pictures for viewing on a television-like display. IR imagers can identify "hot spots" in laminated wood members indicating areas of delaminated bonding. Low skill level sufficient for operation; considerable expertise required to interpret images, unless enhanced by a color graphics software program.

*** Refer to Appendix D for information on suppliers.**

Table E7

Metals and Connections

PROPERTY	ACCEPTABLE NDE METHOD	INSTRUMENTATION INVESTIGATED	MFR. REF. NO.*	DESCRIPTION OF OPERATION AND LEVEL OF USER EXPERTISE REQUIRED
1. Presence and location in other materials	Magnetic Field	FR-Rebar Locator	10	Presence of steel affects the magnetic field induced by the probe. The closer the probe is to the imbedded steel, the greater the effect. Identifies the size, position, and depth of imbedded rebar. Will locate ferrous-base material including rebar, wire, pipe, sheet metal, conduit, etc. imbedded or placed in another non-ferrous material. Moderate skill required to operate and interpret the readings.
	Videoscope	Video Probe 2000	38	A flexible fiber-optic cable with an attached CCD color camera at the tip produces real-time video images on a high resolution color monitor. Inspection areas can be videotaped for identifying the presence and location of imbedded reinforcement. Low skill sufficient for operation and assessment.
2. Corrosion condition of rebar	Ultrasonic Pulse Echo	Panametrics Digital Ultrasonic Corrosion Gage Model 26DL	22	Pulsed compressional waves be induced into the metal at regular timed intervals. When the pulses encounter a reflecting surface or boundary, a fixed amount of energy is reflected back. The proportion of energy reflected back is monitored and measured and is proportional to the remaining thickness of the metal. Thus, pipes and tanks may be inspected for eroded conditions without dismantling. Both the receiving and transmitting transducers are contained in one probe. With its built-in micro-processor, only a moderate skill level is required to operate and interpret the readings.

*** Refer to Appendix D for information on suppliers.**

GLOSSARY

Acceleration: Time rate of change of velocity, often sensed by a piezoelectric crystal reacting to the inertial strain of a small mass.

Asset: Any item carried on the inventory of an Army installation.

Attitude: Orientation with reference to three orthogonal axes, sensed by referencing to some constant physical phenomena (light/gravity/magnetic field/etc.).

Condition Monitoring: The continuous or periodic monitoring of operating parameters which are known to be indicative of the general condition of a plant, system or unit.

Dielectric: Materials with extremely low electrical conductance properties.

Displacement: A vector representing a change in position with respect to a reference point. Linear D. is displacement with a constant direction. Angular D. is rotational displacement between two coplanar vectors.

Integrated Unit (IU): Where no connections are required by the instrumentation device to perform its sensor/measurement function.

Instrument: A device for performing a measurement or the application of such devices.

Light: Visible electromagnetic radiation between 10E-2 and 10E-6 cm.

Measurement: Measurement is the application of a scale to the output response of a sensor reacting to a physical phenomenon.

Measurement Control: Space-time coordination of the processed measurement signal.

Measurement Data Processing: The acceptance, transformation, and release (transmission) of measurement signals. For example, digital to digital (D/D) data processing can result in signal restructuring prior to providing a measurement readout.

Measurement Programmers: Hardware used to convert electrical signals from analog to digital or reverse.

Measurement Result or Readout: The visible record provided to the instrument user.

Measurement Signal: The physical phenomenon detected by the sensor of the measurement system over unit time.

Measurement System: The integrated sensor, signal conversion, scaling, and output systems needed to perform an automated measurement. Typically, industrial measurement systems are identified by the sensor, actuator, or physical phenomenon associated with the measurement.

Piezoelectric Effect: The separation charge in an ionic crystal (such as quartz or barium titanate) under stress creates a potential across the face of the crystal which is the piezoelectric effect.

Sensor: A sensor or sensor transducer usually reacts to a specific exterior signal (physical phenomenon) that is analog in nature, converting this input into an electrical analog or digital signal for processing by some appropriate measurement system. This processing can include signal conversion/control, wave shaping, interpretation/measurement, and eventual display of the output value. Sensors may be classified by their functional characteristics or by the measurement system to which they contribute. Sensors may be used as:

- Direct Indicators:
  —Chemical States
  —Physical States
  —Energy Levels
  —Combinations.

- Indirect Indicators:
  —Key property assessments
  —Response to overlay force/energy
  —Degeneration of known signal.

Resistance Thermal Detector (RTD): A wound wire or metal film (often platinum) with a positive, nearly linear temperature coefficient.

Sound: Pressure waves in a gaseous or liquid media capable of detection in the Human auditory system.

Status: The operating health of a system/unit as determined by a condition monitoring procedure.

Strain: Deformation of a solid resulting from stress.

Stress: The force acting on a unit area of a solid.

Thermistor: An electrical resistor with a high temperature coefficient, designed to indicate temperature changes within a specified range. Good thermistors will have a built in compensation for their nonlinearity.

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117
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